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A scenario approach for ecosystem-service changes

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ABSTRACT

Future predictions are imperative for environmental planning decisions as ecosystem changes take time to have an effect. In this paper, on the basis of a scenario approach to expose common frameworks and legitimacy, we quantitatively and qualitatively reviewed scientific papers to assess the future condition of ecosystem services. Of the 464 recent papers on biodiversity and ecosystem service changes, we extracted 106 papers by excluding papers that only examined climate change and/or carbon dioxide. Of the 106 papers, most used three scenarios to assess changes in from two to four ecosystem services over the next 20 to 30 years. Overall, not all of the scenarios were used in a predictive capacity, and of the ecosystem services examined, regulating and provisioning services were analyzed more frequently than cultural services. In practice, when using the outcomes of this scenario approach, either an administrative unit or a basin approach is an advisable scale for decision making. As a basin includes various micro ecosystems and various stakeholders, a participatory approach is the most favored.

1. Introduction

Future predictions are imperative for environmental planning decision-making as ecosystem changes take some time to become apparent. For instance, climate change, which has been a concern since the 1960s, may have begun decades ago to reduce habitats and threaten species (Malcolm, Liu, Neilson, Hansen, & Hannah, 2006; Menéndez et al., 2006; Parmesan et al., 1999). Future economic, land use, and urbanization changes require a long-term perspective and need to consider other factors such as possible new technologies and innovations, demographic and cultural changes, and socio-economic developments. Environmental policy decision-making in this complex situation should consider both rapid and slow changes and develop comprehensive methods for future-oriented approaches (Burnett, Fall, Tomppo, & Kalliola, 2003; Ratcliffe & Krawczyk, 2011; Stojanovic, Mitkovic, & Mitkovic, 2014).

The scenario approach is one of the tools that can support such decision making (Bradfield, Wright, Burt, Cairns, & Van Der Heijden, 2005; Kepner, Hernandez, Semmens, & Goodrich, 2007). Research has shown that the development of environmental scenarios could reduce uncertainty by providing plausible alternative paths (Bradfield et al., 2005; Bishop, Hines, & Collins, 2007), and allow for deeper, more focused investigations (van Notten, Rotmans, van Asselt, & Rothman, 2003). This approach is particularly useful when dealing with uncertainty, as we lack sufficient information about the probability that different events may occur (Durance & Godet, 2010). For global land systems, this approach is at the core of several assessments such as the Millennium Ecosystem Assessment (MEA) (Carpenter, Bennett, & Peterson, 2006), the global environmental outlook GEO4 (UNEP, 2007), and various sub-global investigations (Seppelt, Lautenbach, & Volk, 2013). Besides its obvious planning advantages, scenario analysis is also an effective learning tool, as it helps us to understand the development logic and to identify the driving forces (Amer, Daim, &

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Jetter, 2013). In environmental science, research on the scenario approach has been increasing since the 1990s, and has accelerated since the 2000 s (Celeste Amorim Varum, 2010). The characteristics of recent social scenarios are longer prediction periods, wider scale ranges, the inclusion of multiple factors and stakeholder participation (Holway et al., 2012; Maui, Kanamori, & Harasawa, 2007). These trends may also be applicable to ecosystem service (ES) scenarios (Malinga, Gordon, Lindborg, & Jewitt, 2013)

To determine the recent trends in ecosystem service scenarios at the global and local scales, in our review of the papers that assessed changes in ES, we focused on two main challenges to develop the environmental studies scenario story-lines: frame-works (e.g., assessment scales, future years, drivers) and legitimacy (who developed the scenarios and how). For ecosystem service changes, we targeted land use changes as the main driver based on former studies (Albaladejo et al., 2013; Cotter et al., 2014; de Chazal and Rounsevell, 2009; Sala, 2000). We also validate if scenarios were used in a predictive capacity and examined the types of scenarios and scenario building common to ES approaches.

2. Methods

A comprehensive assessment of existing academic research on scenario approaches for terrestrial ES changes with socio-ecological aspects was conducted to identify the structure, with a specific focus on macro and micro ES scales and prediction periods.

For this review, we included studies based on case studies or field work but rejected literature reviews or meta-analyses of previously published data to avoid double counting. By interrogating the citation database “Web of Science,” we filtered articles on biodiversity and ES published in journals before 2014. The search strings used were: “scenario*” and “biological-diversity* or biodiversity* or ecosystem*” and “land-use* or land-cover*.” However, we did not include “climate* or warm* or CO^2 or carbon*” as we did not intend to focus on “climate change.” We targeted the term “land use” as the strongest driver for distortions in ecosystem services (de Chazal & Rounsevell, 2009; Haines-Young, 2009; Hu, Wu, Hong, Qiu, & Qi, 2013). The preliminary search using “Web of Science” with the terms “climate* or warm* or CO^2 or carbon*” identified inappropriate papers for our study; therefore, these terms were subsequently excluded from the search. Although papers that discussed ES were included, only those that addressed biodiversity such as habitat management strategies and/or a certain ecosystem were selected. At the first stage, 464 papers were identified in the Web of Science search, from which 106 papers were finally selected (A1) through an abstract check.

The 106 papers were analyzed from two different perspectives: global and regional ES assessment trends and scenario building methods for assessing ES changes. To identify the assessment trends, three areas were examined; (1) the target ES(s) and the drivers of the changes, (2) the scale of the assessment area/the target ecosystem(s), and (3) the assessment duration (years). Ecosystem services were described on two different levels: (1) macro ESs categories, as in the MA (Millennium Ecosystem Assessment), including provisioning, regulating, and cultural services and (2) the micro ES attached to each macro ES, such as crop yields and fiber provisioning services. For the macro ES support services, we only examined biodiversity/habitat because these services had been analyzed multiple times. Vegetation cover and land use types have been commonly analyzed as ES change drivers. Scale was examined at the ecosystem level or the multi-ecosystem level. The ecosystem level included mountains/high land, forests, agricultural areas, arid regions/deserts, urban areas, national parks/protected areas, rivers, and others, and the multi-ecosystem level included administrative units and basins/landscape. We also examined the scales used in Europe, North America, East Asia, Oceania, Southeast Asia, Africa, and Central/South America.

Scenarios were classified into strategic, exploratory, normative, and BAU (business as usual), classifications which have been used in prior studies (Liu et al., 2008; Rounsevell and Metzger, 2010; Stojanovic et al., 2014):

- “Strategic” scenarios identify inconsistencies in different scientific disciplines in a complex system such as in an ecosystem (Liu et al., 2008). This type of scenario is mostly used by scientists working on models. Scenarios that were established quantitatively, such as ambient temperature change scenarios between 2 and 10, degrees Celsius, are strategic.
- “Exploratory” storylines describe the qualitative assumptions about the driver of change. This is the most common scenario used to assess the condition in the future using an existing process model developed from a past condition.
- “Normative” scenarios begin from the desirable future and work back to identify the necessary events in the present.
- “BAU (business as usual)” scenario storylines speculate the future if all conditions remain the same. These are typically used in short-term policy analyses to explore the consequences of relatively well-known and near-term changes in regulatory contexts (Project, 2007).

The scenario class for all 106 papers was determined. As this paper’s focus is on identifying a local adequate scenario approach, after the class was determined, the scenario developer was identified. To finally classify the scenarios, two participant groups were identified; expert(s) or participants with multiple backgrounds, such as academic and research communities, inhabitants or farmers, and people from business sectors such as industry experts, decision makers/governments, and non-profit organizations/non-governmental organizations (NPO/NGO) (Oteros-Rozas et al., 2015; Walz et al., 2007).

3. Results

3.1. Global trends for the scenario approach to ES assessment

All 106 papers assessed quantitative ES changes using two to four scenarios (Fig. 1a). Less than half the papers (43%) specified a set up period (the length of years) in the assessment (Fig. 1b) and those that did had assessments shorter than 50 years in the future,

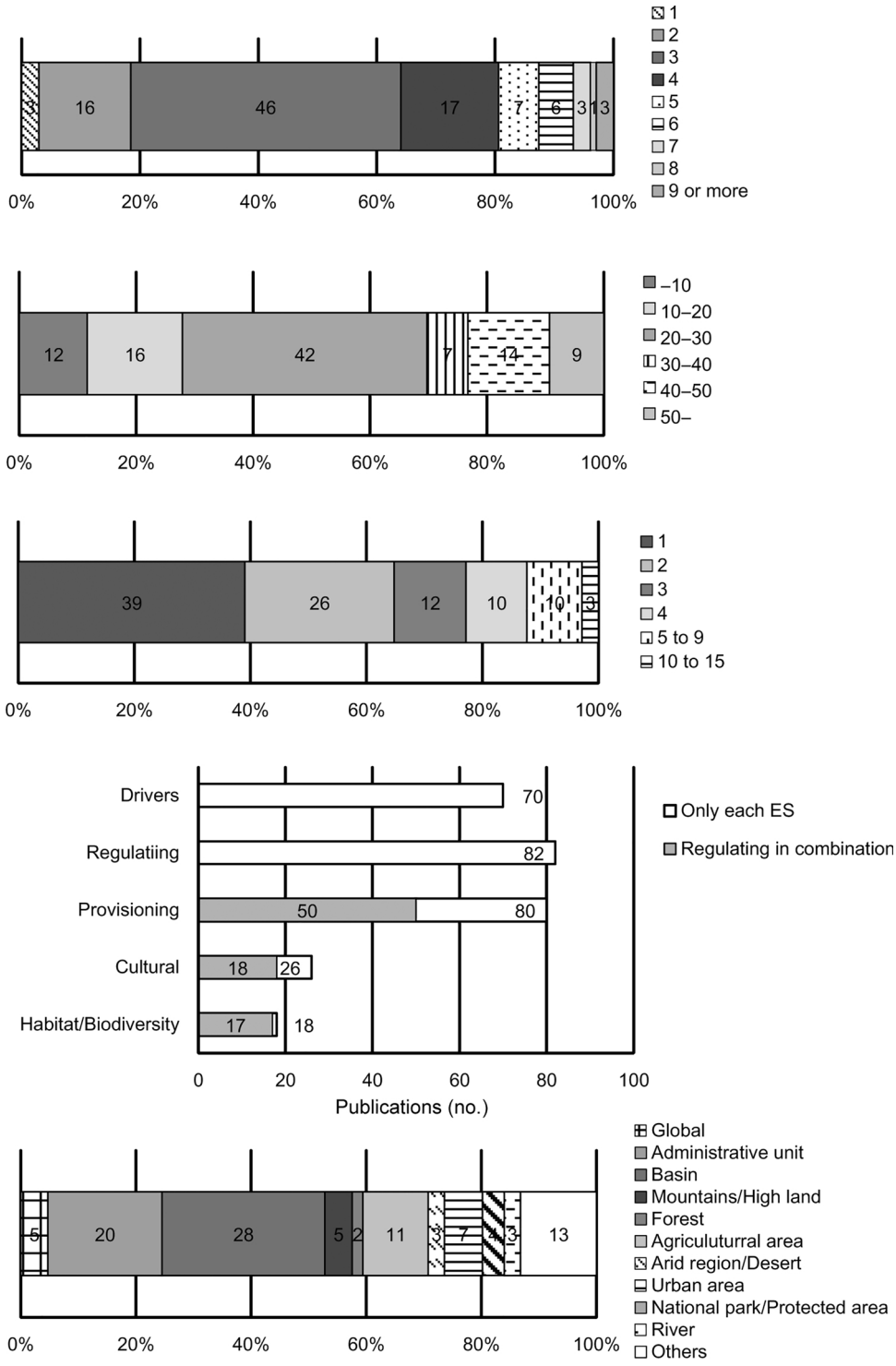

Fig. 1. Global trend of scenario approach for assessing ecosystem-services.
(a) The number of scenarios in a paper (%) (n = 106).
(b) Length of assessment period (years) (%) (n = 43).
(c) The number of ecosystem-services (%) (n = 106).
(d) Types of ecosystem services (n = 106).
(e) Levels to assess ecosystem services (%) (n = 106).

Table 1
Target ecosystem-services of each region.

		Drivers									
	n	Plant coverage/ forest coverage	Land use	Agricultural cover	Feed crop	Urban ecology	Urban expansion	Density of residence	Cultivated ecosystem	Grassland ecosystem	Coastal ecosystems
in	30	χ	χ	χ	χ						
Mountains/ Highland	5	χ	χ					χ			
Forest	4	χ				χ					
Agricultural area	22	χ	χ	χ					χ		
Arid region/Desert	3		χ							χ	χ
Urban area	9	χ	χ			χ	χ				
National park/ Protected area	4	χ	χ	χ							
River	3										
Others	15	χ	χ	χ		χ					

	Regulating services											
	River quality/ quantity	Nitrogen/ phosphorus	Soil erosion	Soil formation	HIV	Carbon accumula-tion	Groundwat-er quality/ quantity	Carbon emission	Clean up air	Fire disaster	Pest	Pollination
in	χ	χ	χ	χ	χ							
Mountains/ Highland		χ				χ	χ	χ				
Forest										χ		
Agricultural area		χ				χ					χ	χ
Arid region/Desert	χ						χ					
Urban area	χ		χ	χ		χ		χ	χ			
National park/ Protected area												
River	χ											
Others	χ	χ	χ				χ		χ			

	Regulating services	Provisioning services										
	Hydro power	Crop yield	Agricultural income	food	Timber/ Biomass	Mineral resource	Renewable energy	Agricultural price	Feed	Home energy	Industrial energy	Clean air
in		χ	χ	χ	χ	χ						
Mountains/ Highland		χ	χ	χ	χ			χ		χ	χ	
Forest		χ			χ		χ					
Agricultural area		χ	χ	χ			χ		χ			
Arid region/Desert		χ										

(*continued on next page*)

Table 1 (*continued*)

	Regulating services	Provisioning services										
	Hydro power	Crop yield	Agricultural income	food	Timber/ Biomass	Mineral resource	Renewable energy	Agricultural price	Feed	Home energy	Industrial energy	Clean air
Urban area		χ		χ		χ	χ					
National park/ Protected area		χ	χ									
River		χ	χ									
Others	χ	χ	χ	χ	χ	χ	χ	χ				χ

	Provisioning services	Cultural services						Biodiversity/Habitat conservation					
	Fiber	Ecotourism/ Recreation	Esthetic aspects	Value of legacy	Social shaping	Education	Health	Bird	Mammal	Fish	Evaluated habitat	Biodiversity	Coral reef
in		χ						χ	χ	χ			
Mountains/ Highland		χ				**χ**							
Forest												**χ**	
Agricultural area			χ	χ	**χ**			χ			**χ**		
Arid region/Desert											**χ**		
Urban area		χ										**χ**	
National park/ Protected area									χ		**χ**		
River			χ								**χ**		
Others	χ	χ	χ				**χ**	χ				**χ**	**χ**

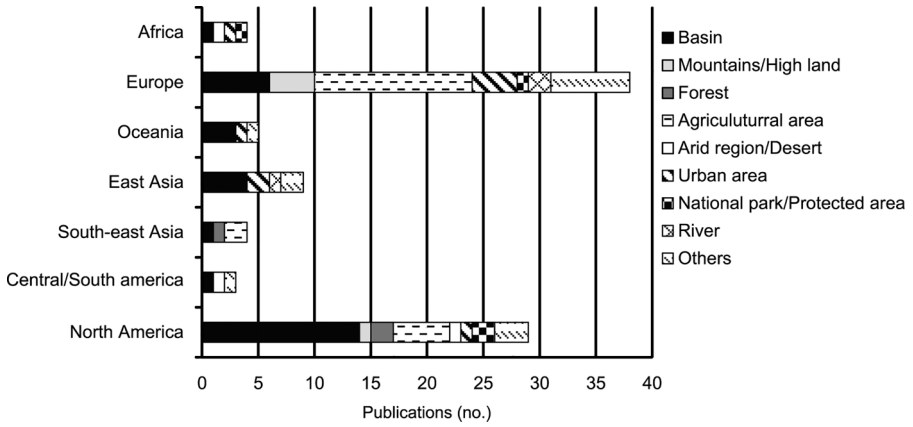

Fig. 2. Boundaries of each region.

with most being only between 20 and 30 years. The papers that dealt with one single ES amounted to 39% of the total papers, but the majority (61%) included multiple services (Fig. 1c). However, most papers tended to include only a small numbers of ES, with only 13% having more than 5. Approximately 40% of the papers addressed a single ecosystem service category from the four macro ES categories used in the MEA (Fig. 1c). Most multi-category papers analyzed a macro category together with a regulation service, although future changes in habitat/biodiversity were rarely discussed (Fig. 1d).

The analysis was conducted for each ecosystem scale or for a multi-ecosystem scales made up of either a landscape or an administrative unit. Many papers examined changes in ecosystem types (54%), while the others analyzed changes in either a landscape such as a basin, or at an administrative unit level (Fig. 1e). For the ecosystem types, anthropologically disturbed ecosystems such as urban areas (3%) and agricultural lands (3%) were less focused on than natural to semi-natural ecosystems, although natural and/or human disturbed basin ESs dominated. Although basins include several ecosystems, the ES that were analyzed at the basin scale were not necessarily the same as those on the ecosystem scale (Table 1). This was particularly noticeable in cultural services, in which the number of micro-services dealt with was smaller than those on the ecosystem scales.

In the regulating services, river quality/quantity (30 papers) was the most assessed service, followed by nitrogen/phosphorus (10 papers), groundwater quality/quantity (4 papers), carbon emissions (4papers), soil erosion (4 papers), and soil formation (4 papers), with one paper looking at another aspect. In the provisioning services, crop yield (24 papers) was the most assessed service, followed by food (14 papers), agricultural income (12 papers; include agricultural prices), renewable energy (11 papers), timber/biomass (4 papers), and mineral resources (4 papers), with one paper looking at another aspect. In the cultural services, ecotourism/recreation (9 papers) was the most assessed service, followed by esthetic aspects (6 papers), with one paper looking at another aspect. In the biodiversity/habitat conservation, which was also considered an independent service, habitat assessment (4 papers), evaluation biodiversity (4 papers), and birds (4papers) were common in the scenario approach, followed by mammals (2 papers), with one paper looking at another aspect (Fig. 2).

3.2. Regional trends in the scenario approach to assess ES

Multiple ES analyses were common in the EU, North America, and East Asia. The numbers of analyzed macro ES and the foci in each region were: For Africa, there were 3 papers on drivers, 2 papers on regulating, 1 paper on provisioning, 1 paper on cultural, and 1 paper on biodiversity/habitat; for Europe the numbers were 28, 23, 33, 15, and 6; for Oceania, 2, 4, 5, 0, and 1; for East Asia, 10, 15, 14, 3, and 3; for South-east Asia, 4, 2, 2, 0, and 0; for Central/South America, 5, 0, 2, 0, and 2; and for North America, 12, 27, 16, 1, and 5, respectively. Regulating services appeared to be of most concern in all regions.

At the basin level, 27, 13, 1, 15, and 3 papers were respectively focused on drivers, regulating, provisioning, cultural, and biodiversity/habitat, with analyzed ecosystems in each region for each focus being mountain/highlands, 5, 10, 5, 4, and 0; forests, 0, 2, 0, 3, and 1; agricultural areas, 5, 21, 4, 15, and 3; arid area, 2, 1, 0, 3, and 1; urban area, 13, 6, 4, 7, and 2; national park/protected area, 0, 2, 0, 4, and 2; river, 2, 3, 1, 0, and 1; others, 13, 15, 5, 8, and 3.

3.3. Methodological trends for scenario building

Seventy papers used an exploratory original method, with 17% focused on participatory methods, 3% on expert judgment, and 80% being researcher led; moreover, 19 papers focused on a strategic method, with 11% focused on participatory methods, 11% on expert judgment, and 79% being researcher led (Fig. 3). Although participatory methods were not necessarily the most common method, they were frequently used in agricultural and urban areas as well as in multi-ecosystems at the basin level. In most cases, researchers built scenarios in collaboration with multi-stakeholders including farmers (11), decision makers/government (9), and business sectors and nonprofit organizations (8) (the numbers in parentheses indicate the cases in which they participated).

To analyze the ES, at the basin level, exploratory original research methods were the most common followed by strategic research

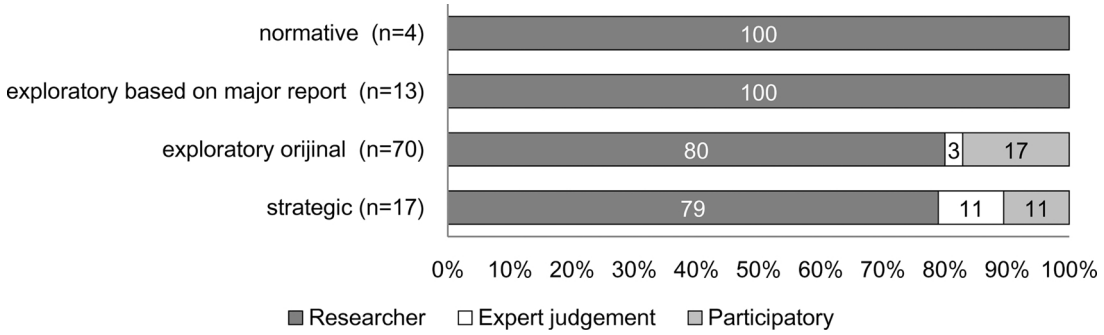

Fig. 3. Types of scenario building methodology.

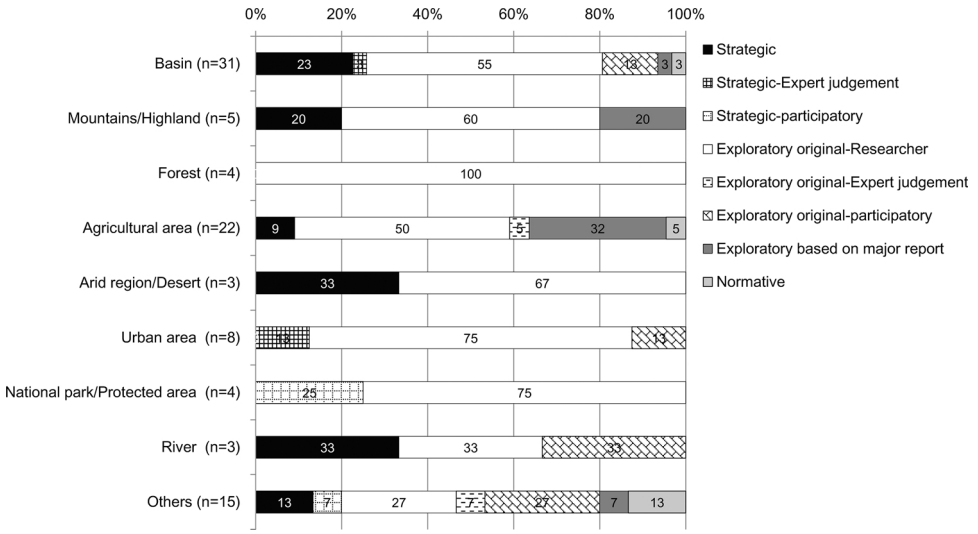

Fig. 4. Methods used for each ecosystem type.

methods, exploratory methods based on a major paper, and exploratory original methods with participation (Fig. 4). In the agricultural areas, exploratory original research methods were generally used (50%, n = 22), followed by exploratory methods based on a major paper (32%). In the urban areas, exploratory original research methods were generally used (75%, n = 8).

4. Discussion

4.1. Global trends in the scenario approach to assessing ES

Although a previous study concluded that three to eight scenarios was the standard approach (Pillkahn 2008), our results showed that most scenario approach papers included two to four scenarios for future assessments (Fig. 1a), with three scenarios being the most common for BAU and other extreme scenarios assessing social trends and land use planning in local regions (Grantham, Mezzatesta, Newburn, & Merenlender, 2014; Hilde & Paterson 2014; Luo, Zhan, Lin, & Zhao, 2014). However, more than five scenarios have been seen to be costly and therefore not often employed (Pillkahn 2008). In the scenario approaches, an assessment of 3–20 years used to be common (Bradfield et al., 2005) but in ES today, more than 20 years was more common (Fig. 1b), probably because the drivers of the ES changes identified in the papers were land use changes after several decades of use (Eickhout & Prin 2008). EURURALIS, which is the land use plan in Europe, was not the only example to consider 2030 as the year for end of the plan (Fischer et al., 2010; Hellmann and Verburg, 2010). Although environmental changes take a relatively long time, assessments of 50 years have been considered too long for most researchers (Arbault, Riviere, Rugani, Benetto, & Tiruta-Barna, 2014). In scenario approaches that included ES, the number of analyses examining tradeoffs or synergies between different ES has been increasing (Carpenter et al., 2006). Although tradeoff/synergy analyses that include multiple ES are useful, the trends show that the most common analyses are focused on the most important ES for the local regions, possibly because of technical quantitative challenges and the need for reliable approaches.

Overall, in the ES in the papers we examined, regulating and provisioning services were analyzed more frequently than cultural services, possibly because the former were able to be quantified as this is more difficult with cultural services (Union, 2014). However, appropriate scale was more easily determined for cultural services than for the others because of the complex relationships

between services (Union, 2014). In practice, to use the outcomes of a scenario approach, either an administrative unit or a basin was the recommended scale for decision making. To choose better policies, tradeoffs or synergies between ES should be carefully considered for a certain time in the future. Another trend found was economic assessments for future assessments on ES changes. A number of methods have been developed for ecosystem economic assessment, one of which is the ecological footprint that can correspond with different scales and also identify the interactions between ES and ES, and between ES and policy implementation (Elmqvist et al., 2013). For economic value studies, cultural services tended to be limited to those that could be converted into economic value, such as tourism.

4.2. Regional trends in the scenario approach to assess ES

The ecosystems analyzed in each of the region most often highlighted particular interests. The European focus on agricultural land may reflect the ratio of profit from different uses and industry (Everaars, Frank, & Huth, 2014; Gómez Sal & González García, 2007; Haines-Young, Potschin, & Kienast, 2012). However, in East Asia, even though agricultural production is still growing, urban areas were the most analyzed, probably because of the recent rapid urbanization (Seto, Fragkias, Guneralp, & Reilly, 2011). North America, however, differed from the other regions, as research was more focused on the integration of ecosystems and the analysis of changes at the landscape level (Coiner, Wu, & Polasky, 2001; Grantham et al., 2014; Kepner et al., 2012; Runfola et al., 2013). Although regional trends reflected the current societal interests in each region, it is necessary to have a more integrated perspective to assess ecosystems at the landscape level to avoid ecosystem fragmentation.

4.3. Methodological trends in scenario building

Although the exploratory scenario has been generally considered a single type, the characteristics of an explanatory scenario with and without an original scenario were clearly different in terms of actual numbers of cases, the number of scenarios analyzed, and the types of scenario builders (Fig. 3). Participatory scenario building has also been important, particularly for decision making (Máñez Costa 2011; Malinga et al., 2013; Plieninger et al., 2013). We found that the participatory scenario approach was commonly used to assess the future at the landscape level and also for rivers, urban areas, and national parks/protected areas (Fig. 4), which suggests that ecosystems urgently require either sustainable development or conservation. As a basin encompasses various micro ecosystems and stakeholders, the participatory approach was the most favored.

5. Conclusion

The number of ES assessments that include an assessment of future changes using different scenarios/policies has been increasing. However, probably because of the technical restrictions, future assessments have been limited to the small scale ecosystem level, and not all of the scenarios were used in a predictive capacity. To properly assess ES, we need to develop sound measures to integrate assessments from different ecosystems, particularly for ES at the upper and lower streams in a basin. We also suggest that science-policy platforms that include society and multiple-stakeholders be included in future scenario analyses.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.futures.2017.11.003.

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